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DEVELOPMENT OF THE VARIABLE CONFINEMENT COOKOFF TEST

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The Variable Confinement Cookoff Test (VCCT) was developed to provide a low cost, small-scale method for evaluating the response of energetic materials to thermal stimuli. Confinement of test samples may also be varied to evaluate its effect on reaction behavior. This report documents the configuration, test procedures, and test results obtained to date for the VCCT.

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FOREWORD

The work reported herein was performed at the Indian Head Division, Naval Surface Warfare Center, Indian Head, MD. The effort was sponsored by the Navy's Insensitive Munitions Advanced Development Program-High Explosive Project. Individuals who were instrumental in the development of the test were Mr. T. Spivak and Mr. A. Gillis.

Approved and released by:

Kurt F. Mueller

Kurt Mueller
Head, Energetic Materials Research
and Technology Department

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INTRODUCTION

The Variable Confinement Cookoff Test (VCCT) was developed as an inexpensive test procedure which may be used to evaluate the effects of confinement on the thermal behavior of energetic materials. It was developed based on a modification of the Small Scale Cookoff Bomb (SSCB) developed by Jack Pakulak.[1] By providing a method for determining reaction severity of an energetic material as a function of confinement, results may be used in weapon design to enhance weapon vulnerability and platform survivability. Additionally, the test allows direct comparison of the results with other materials tested in the same test fixture. Initially, the VCCT was designed to study the effects of a slow cookoff environment upon candidate materials; however, recent efforts have also included evaluation of a simulated fast cookoff test requiring a few modifications to the existing hardware configuration. The intent of this report is to document the final configuration and test procedures of the VCCT as well as to summarize the results of all energetic materials tested to date.

[1]Pakulak, Jack, NWC TP6414, "Calibration of a Super Small-Scale Cookoff Bomb (SSCB) for Predicting Severity of the Cookoff Reaction," Naval Weapons Center, July 1983.

TEST DESCRIPTION

A cross-sectional view of the VCCT test unit is shown in Figure 1. A 1-inch-diameter by 2.5-inch-long explosive billet is contained within a 0.012-inch-thick aluminum sleeve. This may either be a single charge or two charges providing the same overall length. Two 0.045-inch-diameter thermocouples are potted in two grooves spaced 180 degrees apart, which run the length of the aluminum sleeve such that the thermocouple beads are positioned at the midpoint of the sleeve. In this manner, one thermocouple is used to control the temperature of the test unit and the other continuously monitors the temperature as the test proceeds. The aluminum sleeve is centered within a steel confinement sleeve of variable thickness with steel washers. The thickness of the confinement sleeve may be varied from 0.015 to 0.120 inch in increments of 0.015 inch. For steel sleeve thicknesses up to 0.090 inch, the assembly is sandwiched between two 0.375-inch mild steel witness plates, which are recessed to preclude venting. Burst pressure calculations have shown that for sleeve thicknesses greater than 0.096 inch, thicker witness plates are required to ensure that the sleeve is the weak link in the assembly. For this reason, 0.50-inch-thick steel plates are used with steel sleeves having thicknesses greater than or equal to 0.090 inch. Four 1/4–20 bolts rated at 150 ksi are used to secure the plates, each bolt is torqued to 30 in-lb. Heating of the assembled test unit is achieved using a laboratory oven or through the use of two 1-inch-diameter, 110-volt, 125-watt mica heating bands at a slow cookoff rate of 3.3 °C per hour. Fast cookoff heating levels are generated through the use of 0.032-inch-diameter nichrome wire wrapped around the length of the test apparatus using an applied voltage of 115 VAC. Component level drawings for the VCCT hardware are provided in Figures 2 through 5.

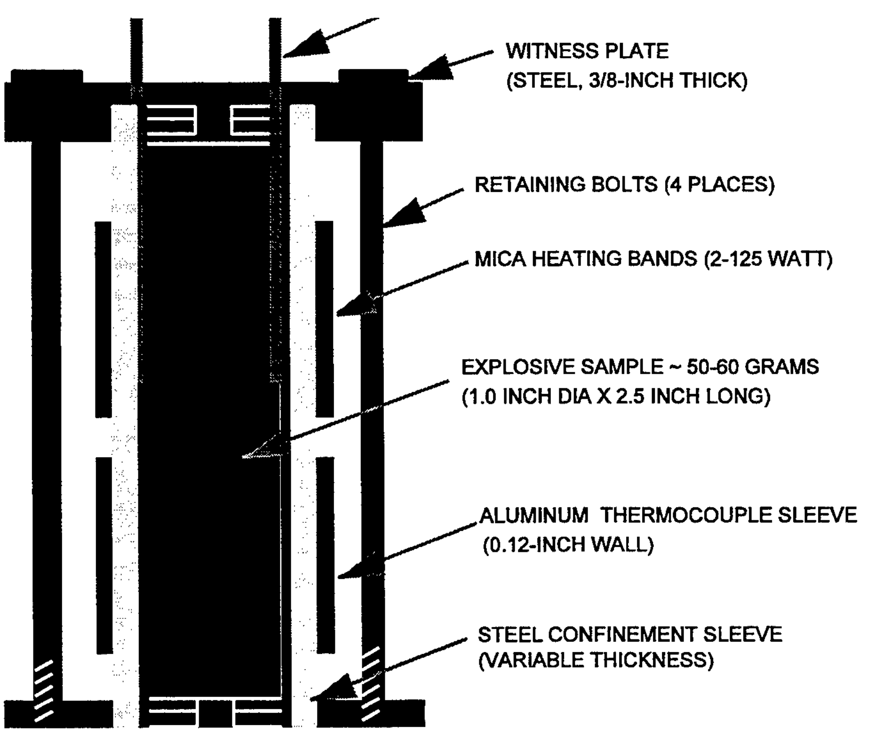


FIGURE 1. VARIABLE CONFINEMENT COOKOFF TEST ASSEMBLY

NOTES:

1. Material:
   Mild steel (seamless)
   Y.S. 79 ± ksi
   U.S. 90 ± ksi
   Enlong. 14 ± 2%
2. External diameter for T105 & T120 is 1.375 ± 0.002 inch

PC NO.	T-DIA (IN)
T15	1.160
T30	1.190
T45	1.220
T60	1.250
T75	1.280
T90	1.310
T105	1.340
T120	1.370

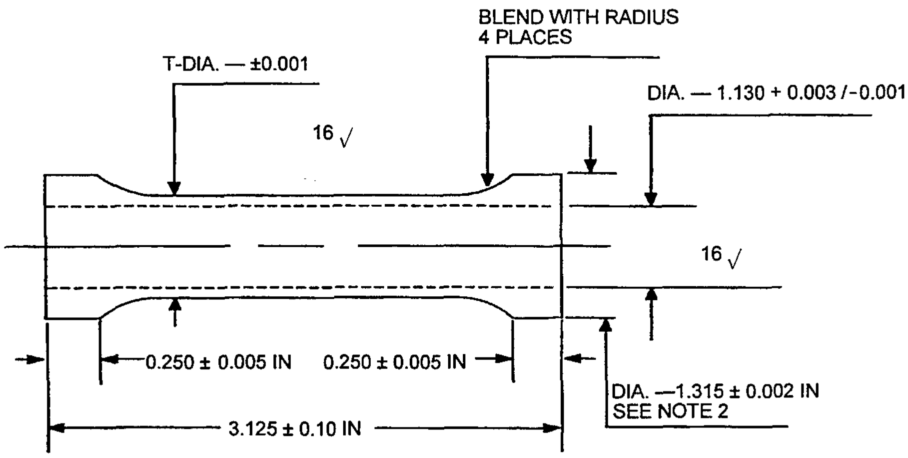
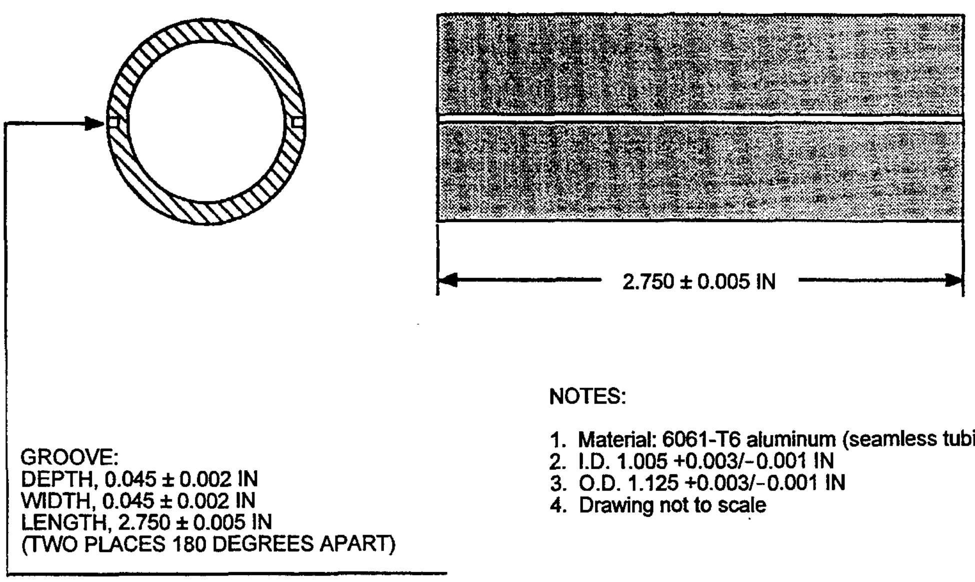


FIGURE 2. CONFINEMENT SLEEVE



NOTES:

1. Material: 6061-T6 aluminum (seamless tubing)
2. I.D. 1.005 +0.003/-0.001 IN
3. O.D. 1.125 +0.003/-0.001 IN
4. Drawing not to scale

FIGURE 3. THERMAL SLEEVE

NOTES:

1. Material; mild steel (seamless).
2. Every other end plate will be tapped for UNC 1/4-20.
3. Break corners and sharp edges 0.05 R, except where specified.
4. Drawing not to scale.

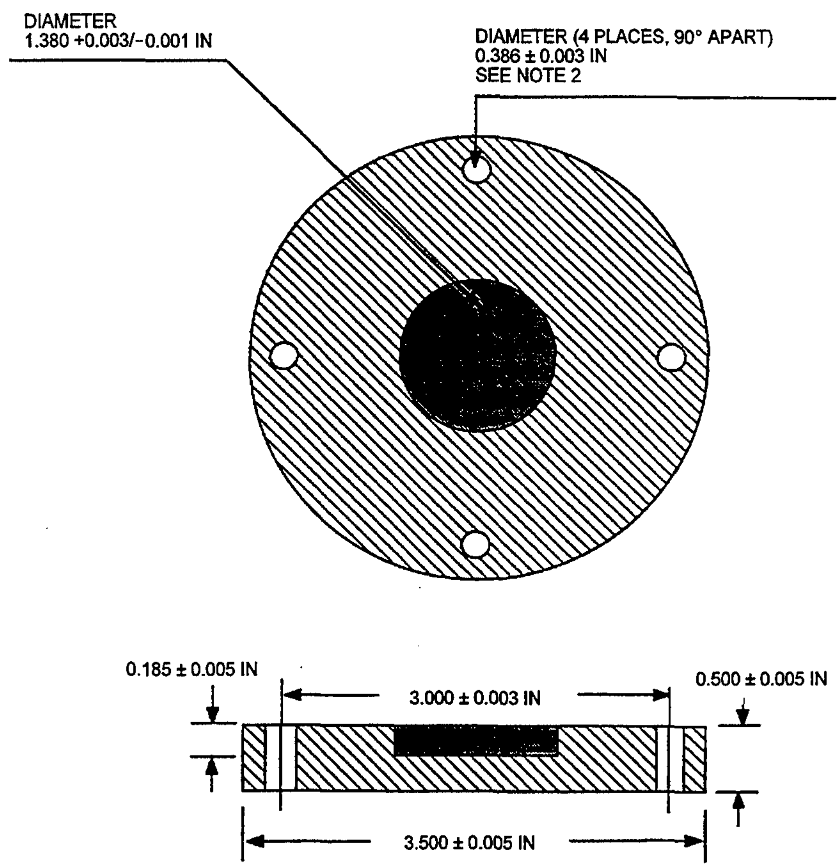


FIGURE 4. END PLATE (0.105 AND 0.120 VCCT)

NOTES:

1. Material; mild steel (seamless).
2. Every other end plate will be tapped for UNC 1/4-20.
3. Break corners and sharp edges 0.05 R, except where specified.
4. Drawing not to scale.

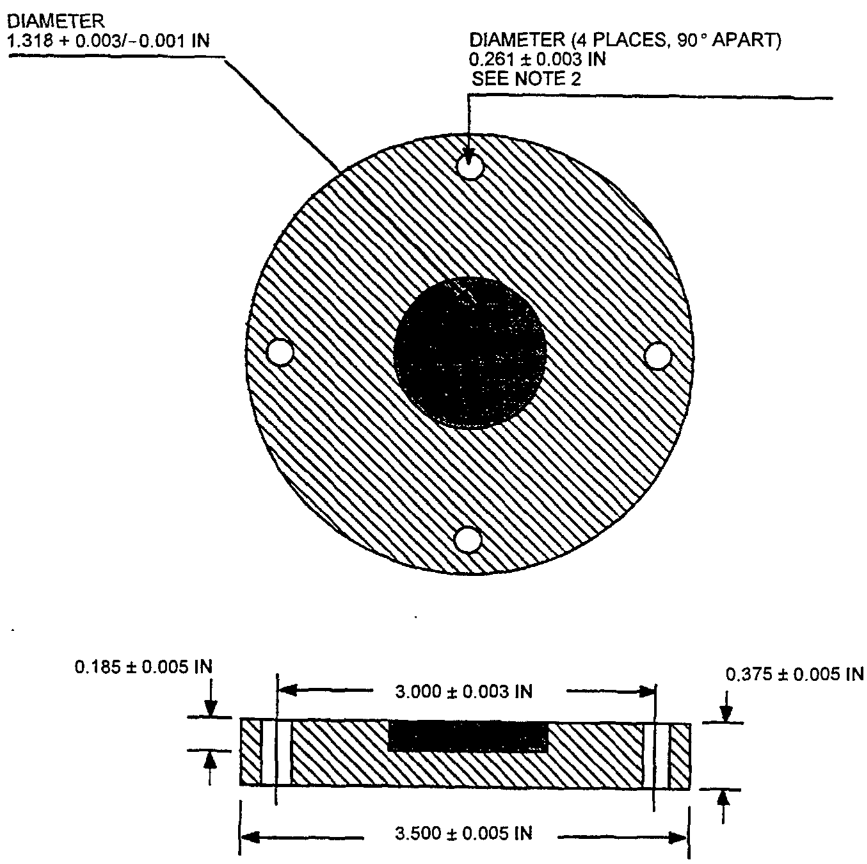


FIGURE 5. END PLATE (0.015 THROUGH 0.090 THICKNESS CONFINEMENT VCCT)

Hydrostatic pressure measurements were made for the VCCT test assembly using steel confinement sleeve thicknesses from 0.015 to 0.075 inch to validate burst pressure calculations that were performed during development of the unit. The calculated and empirical internal burst pressure values are tabulated in Table I and show good agreement. For reporting purposes, the measured values are typically used.

TABLE I. BURST PRESSURE VALUES

Confinement sleeve thickness (in)[a]	Calculated burst pressure (psi)	Measured burst pressure (psi)
0.00 steel	1,331	1,200
0.015 steel	2,507	2,350
0.030 steel	5,150	5,230
0.045 steel	7,795	7,725
0.060 steel	10,270	10,000
0.075 steel	12,999	12,700
0.090 steel	15,305	—
0.105 steel	17,634	—
0.120 steel	19,963	—

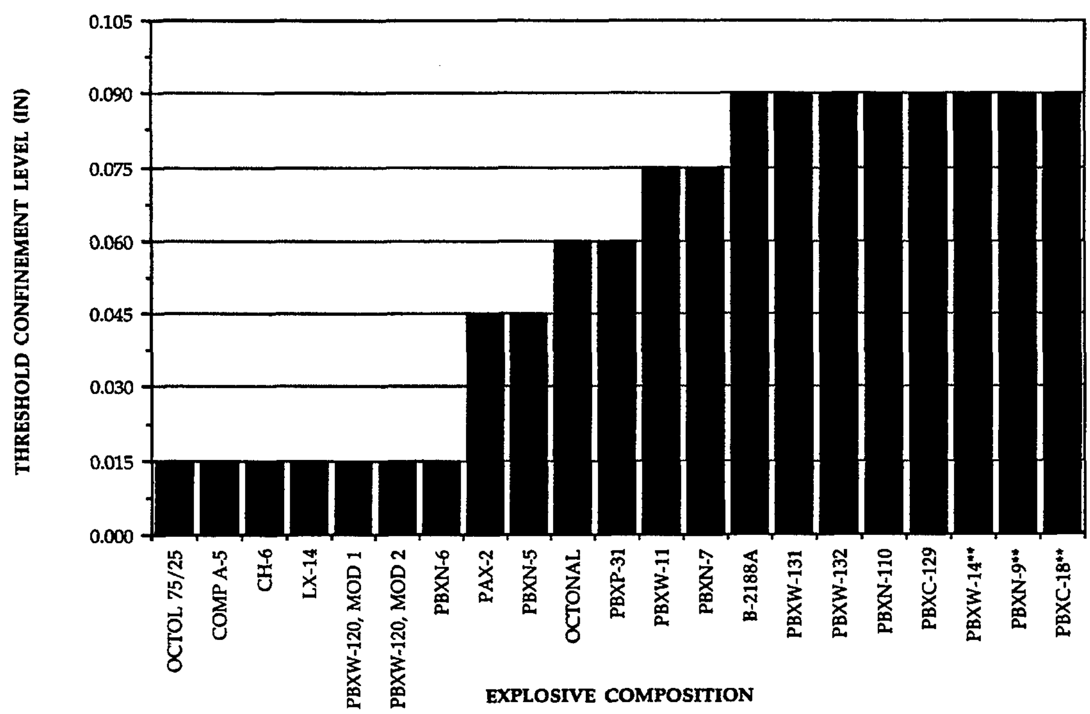
[a]Burst pressure calculations include added confinement presented by aluminum sleeve.

The VCCT test sequence starts by evaluating the behavior of an explosive sample at a predetermined level of confinement. The temperature of the test unit is set at 55 °C below the expected cookoff temperature and maintained at this temperature for 2 hours. The temperature is then increased at a linear rate of 3.3 °C per hour until reaction occurs. The reaction level is noted and the test repeated in step intervals with a steel sleeve of another thickness (i.e., 0.015 inch thicker or thinner). The equivalent pressure of the confinement level, at which the threshold occurs from a pressure rupture to a more severe reaction, is used as a means of ranking explosives in terms of slow cookoff behavior. Based upon data collected from several test series, guidelines were established to interpret VCCT results; these are given in Appendix A. The reaction levels have been instituted such that they are compatible with the definitions described in MIL-STD-2105B and are categorized as follows: burn, deflagration, explosion, partial detonation, and detonation. The more extreme characteristic that would be tolerated as a nonviolent reaction were determined as follows: no more than three large fragments of the steel sleeve recovered, no deformation of the witness plates, and shearing of only two of the retaining bolts. Therefore, at least two of these properties must be evidenced in the event of a pressure rupture. While crossover tendencies may occur in the analysis of VCCT results, the guidelines address the majority of the reactions that have been encountered thus far. The key conclusions obtained from the test provide a method for observing reaction severity trends as confinement is increased.

TEST RESULTS

Slow Cookoff:

A summary of VCCT slow cookoff test results compiled to date is presented in Figure 6. Data are provided for the confinement level for which the material under test first demonstrated a violent reaction. For PBXN-9, PBXW-14, B-2188A, and PBXC-18, failing reactions were never achieved, therefore the confinement levels reported are the most rigorous under which these explosives were tested. The materials evaluated to date are used primarily for metal accelerating and booster applications; their compositions are provided in Appendix B. Individual test data for each composition tested are provided in Tables II and III. Results show that in most cases, a progressive transition from nonviolent to failing reaction occurred.



*DID NOT ACHIEVE FAILURE, CONFINEMENT LEVEL IS HIGHEST AT WHICH EXPLOSIVE WAS TESTED

FIGURE 6. RESULTS OF BOOSTER AND METAL ACCELERATING EXPLOSIVES

TABLE II. SLOW COOKOFF TEST RESULTS OF BOOSTER EXPLOSIVES

Type	Density (g/cm^3)	Steel cylinder (in)	Burst pressure (psi)	Cookoff temperature (°C)	Result
CH-16	1.65	0.015 wall	2,350	187	Detonation
CH-16	1.65	0.015 wall	2,350	187	Detonation
PBXN-7	1.77	0.060 wall	10,000	182	Pressure rupture
PBXN-7	1.77	0.075 wall	12,700	183	Pressure rupture
PBXN-7	1.77	0.075 wall	12,700	176	Pressure rupture
PBXN-7	1.77	0.075 wall	12,700	185	Deflagration
PBXN-7	1.77	0.090 wall	15,300a	181	Deflagration
PBXN-7	1.77	0.090 wall	15,300[a]	181	Deflagration
PBXN-5	1.79	0.015 wall	2,350	197	Burn
PBXN-5	1.79	0.045 wall	7,725	No data	Burn
PBXN-5	1.79	0.045 wall	7,725	200	Deflagration
PBXN-5	1.79	0.060 wall	10,000	204	Partial detonation
PBXN-5	1.79	0.060 wall	10,000	199	Detonation
PBXN-5	1.79	0.075 wall	12,700	206	Detonation
PBXN-6	1.70	0.015 wall	2,350	189	Explosion
PBXN-6	1.70	0.030 wall	5,230	No data	Detonation
B-2188A	1.63	0.075 wall	12,700	139	Burn
B-2188A	1.63	0.075 wall	12,700	136	Burn
B-2188A	1.63	0.090 wall	15,300[a]	138	Pressure rupture
B-2188A	1.63	0.090 wall	15,300[a]	140	Deflagration
PBXC-18	1.71	0.075 wall	12,700	175	Burn
PBXC-18	1.71	0.090 wall	15,300[a]	176	Pressure rupture
PBXW-14	1.81	0.060 wall	10,000	192	Burn
PBXW-14	1.81	0.060 wall	10,000	199	Pressure rupture
PBXW-14	1.81	0.075 wall	12,700	194	Pressure rupture
PBXW-14	1.81	0.090 wall	15,300[a]	193	Pressure rupture

[a]Calculated value.

TABLE III. SLOW COOKOFF TEST RESULTS OF METAL ACCELERATING EXPLOSIVES

Type	Density (g/cm^3)	Steel cylinder (in)	Burst pressure (psi)	Cookoff temperature (°C)	Result
COMP A-5	1.65	0.015 wall	2,350	187	Partial detonation
COMP A-5	1.65	0.015 wall	2,350	187	Partial detonation
OCTOL	1.808	0.015 wall	2,350	202	Detonation
OCTOL	1.808	0.015 wall	2,350	201	Deflagration
OCTONAL	1.86	0.015 wall	2,350	210	Burn
OCTONAL	1.86	0.030 wall	5,230	212	Pressure rupture
OCTONAL	1.86	0.045 wall	7,725	211	Pressure rupture
OCTONAL	1.86	0.045 wall	7,725	210	Pressure rupture
OCTONAL	1.86	0.060 wall	10,000	210	Deflagration
OCTONAL	1.86	0.075 wall	12,700	212	Deflagration
PBXW-11	1.79	0.030 wall	5,230	177	Burn
PBXW-11	1.79	0.045 wall	7,725	182	Pressure rupture
PBXW-11	1.79	0.045 wall	7,725	183	Pressure rupture
PBXW-11	1.79	0.060 wall	10,000	177	Pressure rupture
PBXW-11	1.79	0.075 wall	12,700	176	Explosion
LX-14	1.81	0.000 wall	1,200	189	Explosion
LX-14	1.81	0.000 wall	1,200	184	Partial detonation
LX-14	1.81	0.015 wall	2,350	183	Partial detonation
LX-14	1.81	0.045 wall	7,725	No data	Detonation
PBXN-9	1.74	0.045 wall	7,725	185	Burn
PBXN-9	1.74	0.060 wall	10,000	185	Burn
PBXN-9	1.74	0.075 wall	12,700	184	Burn
PBXN-9	1.74	0.090 wall	15,305[a]	184	Pressure rupture
PBXW-120, Mod 1	1.78	0.000 wall	1,200	No data	Detonation
PBXW-120, Mod 1	1.78	0.015 wall	2,350	204	Detonation
PBXW-120, Mod 2	1.76	0.000 wall	1,200	196	Detonation
PBXW-120, Mod 2	1.78	0.015 wall	2,350	201	Detonation
PAX-2	1.73	0.015 wall	2,350	182	Burn
PAX-2	1.73	0.030 wall	5,230	181	Pressure rupture
PAX-2	1.73	0.030 wall	5,230	182	Pressure rupture
PAX-2	1.73	0.045 wall	7,725	186	Partial detonation
PBXP-31	1.80	0.030 wall	5,230	191	Pressure rupture
PBXP-31	1.80	0.045 wall	7,725	No data	Pressure rupture
PBXP-31	1.80	0.045 wall	7,725	184	Pressure rupture
PBXP-31	1.80	0.060 wall	10,000	186	Pressure rupture
PBXP-31	1.80	0.060 wall	10,000	189	Deflagration
PBXC-129	1.72	0.075 wall	12,700	182	Burn
PBXC-129	1.72	0.075 wall	12,700	183	Pressure rupture
PBXC-129	1.72	0.090 wall	15,300[a]	184	Deflagration
PBXC-129	1.72	0.090 wall	15,300	182	Deflagration

[a]Calculated value.

Results of slow cookoff testing in the VCCT test fixture have proven successful in discriminating among the cookoff behaviors of explosive materials intended for similar applications. This is perhaps best illustrated in the testing of PBXN-9 and PBXW-11, both HMX-based, metal accelerating materials that have identical binder systems and contain 92% and 96% energetic content respectively. As would be expected, the results of VCCT testing of these two compositions show that PBXN-9 was able to withstand a higher level of confinement than PBXW-11 before failure to meet passing requirements occurred. Therefore, it can be reasoned that the VCCT is sufficiently sensitive to the cookoff behavior of similar explosive materials to be used to comparatively evaluate their cookoff vulnerability with respect to one another.

To increase the versatility of the VCCT, tests were conducted upon both PBXN-7 and PBXN-9 where the test unit was heated in a laboratory oven instead of by the heating bands normally used. Presumably, the results of testing using both heating methods should demonstrate little difference in overall cookoff behavior. In the tests conducted, it was shown that PBXN-7 exhibited a transition from pressure rupture to deflagration at 0.075 inch and PBXN-9 demonstrated pressure ruptures at 0.090 inch, the highest level of confinement with both configurations. Therefore, it appears that either of the two means of heating the VCCT test apparatus may be used interchangeably in performing slow cookoff testing.

Fast Cookoff:

With the success of slow cookoff testing in VCCT hardware, efforts were made to simulate fast cookoff testing so that minimal changes to the test fixture would be required. Since a nonlinear heating rate occurs in an actual fast cookoff test, the objective was established that in keeping with Navy requirements (described in MIL-STD-2105), the exterior surface of the test unit should reach 1,000 °F in 1 minute and maintain an average temperature of at least 1,600 °F for the next 15-minute period following the initial minute. An attempt was made to attain these conditions using the mica heating bands powered by 115-volt alternating current (VAC) that are used for slow cookoff testing. The VCCT test unit was loaded with an inert material (desiccant) and thermocouples were installed beneath the band heaters to monitor the temperature of the external surface. Using this configuration, the heaters were only able to generate a temperature of 500 °F in 15 minutes, significantly less than required for fast cookoff requirements.

Several alternate means of heating inert, loaded VCCT units were then investigated to attain the time and temperature conditions required for fast cookoff. Best results were achieved using a 10-ft length of 0.032-inch-diameter nichrome wire insulated with one layer of 0.10-inch-thick Nextel ceramic braid as the heating element. The wire was tightly wrapped around the steel confinement sleeve and heated using 115-volt alternating current (VAC). In order to satisfy the necessary time constraints required for fast cookoff, it was observed that the total resistance of the wire must measure between 4.2 to 4.5 ohms. A depiction of the VCCT fast cookoff test assembly is shown in Figure 7. Temperature measurements were made by two thermocouples, one located between the heating element and the steel sleeve and the other between the steel and aluminum sleeves. A typical VCCT fast cookoff temperature profile generated by the above method is shown in Figure 8.

Simulated VCCT fast cookoff testing was performed upon the following energetic materials: CH-6, PBXN-5, COMP A-5, PBXW-11, PBXN-7, and LX-14. The post-test condition of the hardware did not fall neatly into the categories of reaction established for slow cookoff testing in the VCCT assembly. As a result, new definitions for fast cookoff testing need to be determined once more test data are collected. In the interim, the results reported herein have been qualitatively assessed with regard to reaction severity. Appendix C provides typical fast cookoff test results.

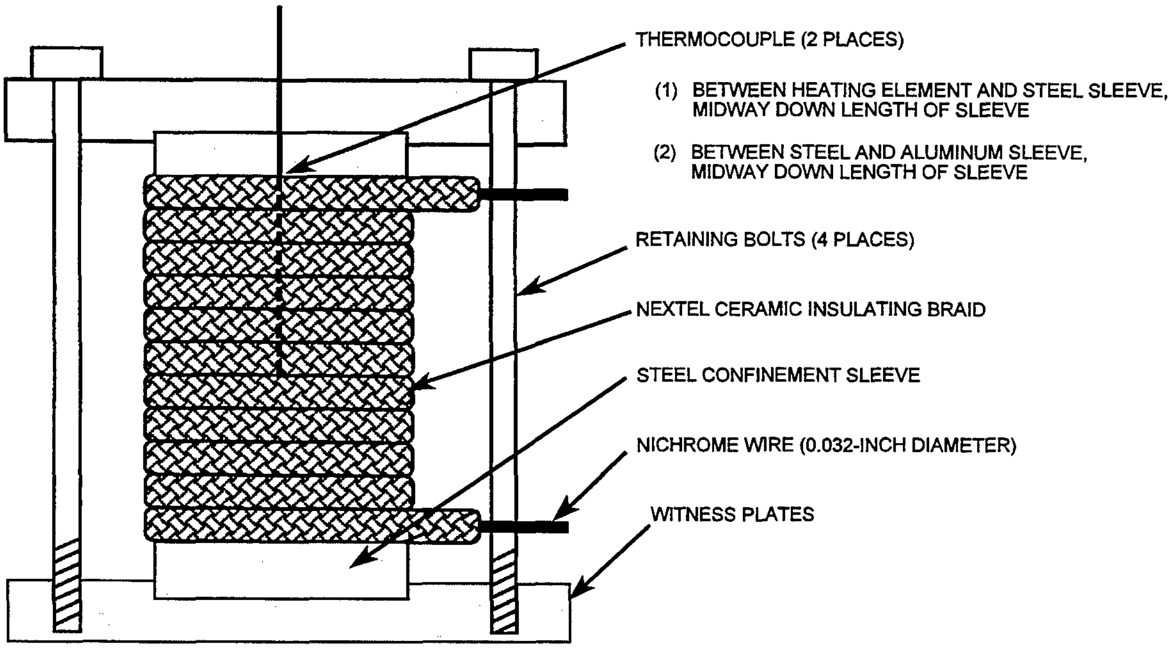


FIGURE 7. TYPICAL VCCT FAST COOKOFF TEST SETUP

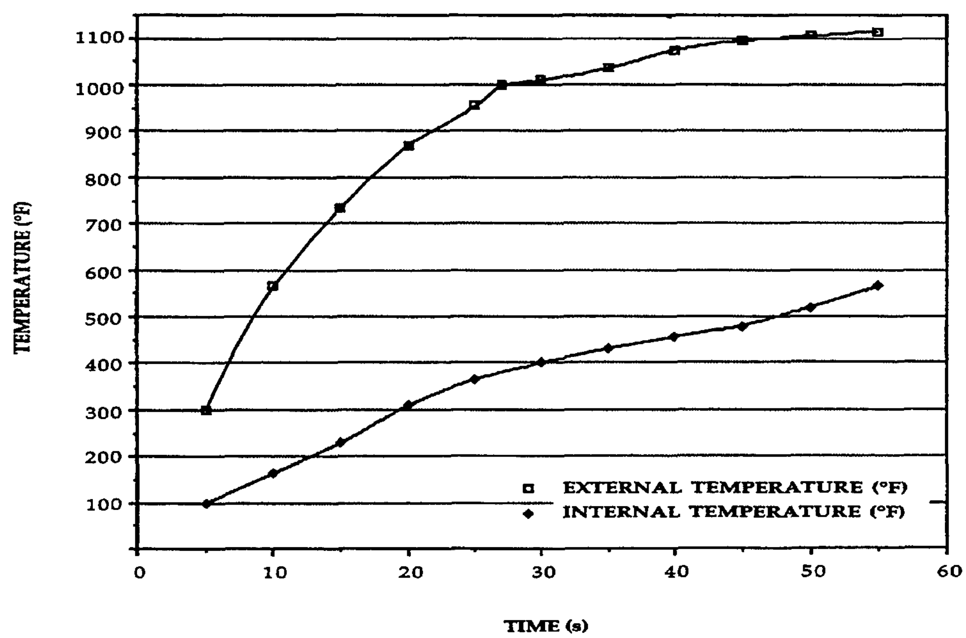


FIGURE 8. NICHROME WIRE HEATING EVALUATION
(110 VAC SUPPLIED VOLTAGE)

CONCLUSION

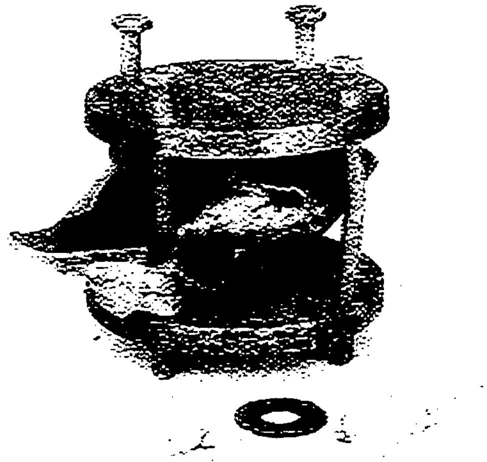
The VCCT has proven itself to be an inexpensive method for evaluating the cookoff behavior of energetic materials at various levels of confinement. Test results for energetic materials correlate well with cookoff studies performed on the same materials in much larger scale generic and tactical hardware. Results have also been shown to be consistent and reproducible. The VCCT may also be used to assist the designer in the prediction of how a candidate explosive may react in a particular weapon configuration. In continuing efforts, slow cookoff testing shall be conducted upon a number of candidate materials to build a database for comparative purposes.

Efforts to simulate fast cookoff testing using the VCCT have proved encouraging. Progress has been made in identifying a heating element such that a simulated fast cookoff rate can be achieved with little modification to the existing hardware assembly. Future efforts in this area will be directed toward further testing of energetic materials in the final configuration and reaction severity modeling.

Based on the successful demonstration of the VCCT, it has been approved as a NATO standardized method (STANAG #4491) for energetic material qualification.

Appendix A

VARIABLE CONFINEMENT COOKOFF TEST GUIDELINES

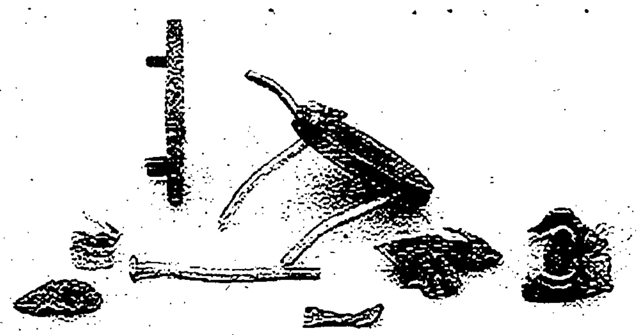


BURN

- Steel sleeve recovered in two pieces or less
- No bolts broken
- No deformation of witness plates

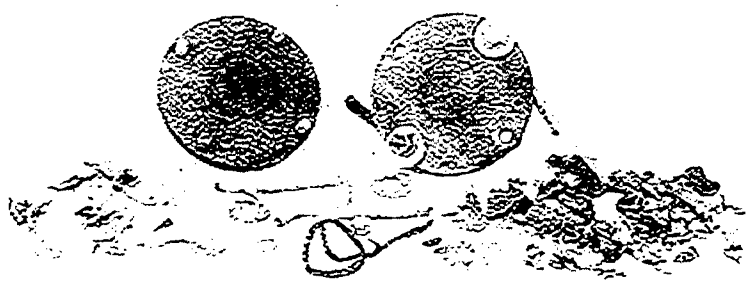
PRESSURE RUPTURE

- Steel sleeve recovered in no more than three large fragments
- No more than two bolts sheared
- No deformation of witness plates



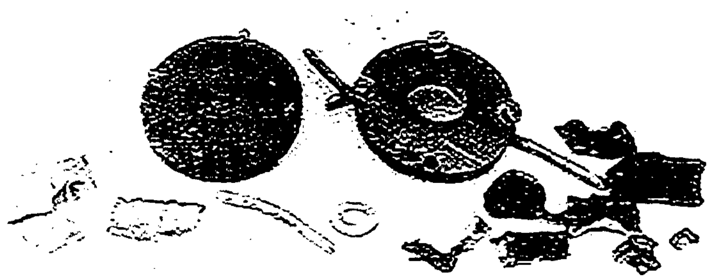
DEFLAGRATION

- Steel sleeve recovered in three or more large fragments
- Two or more bolts sheared
- Deformation of one or both witness plates



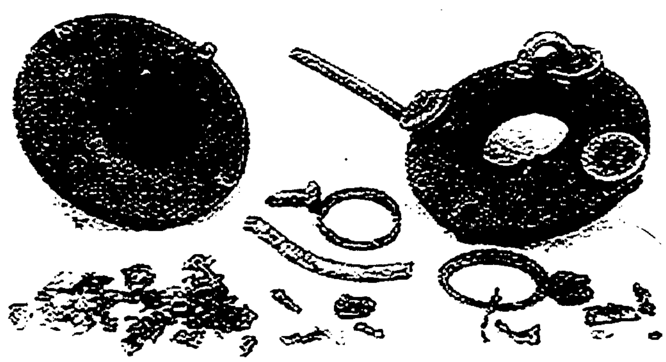
EXPLOSION

- Steel sleeve reduced to numerous small fragments
- All bolts sheared
- Deformation of one or both witness plates



PARTIAL DETONATION

- Steel sleeve reduced to numerous small fragments
- All bolts sheared
- Witness plates recovered with shearing or clean hole in one plate and deformation to shearing in other



DETONATION

- Steel sleeve reduced to numerous small fragments
- All bolts sheared
- Witness plates recovered with a clean hole punched through one plate and at least shearing in the other

Appendix B

COMPOSITIONS OF VCCT-TESTED EXPLOSIVE MATERIALS

Explosive	*Composition*
OCTOL 75/25	75.0% HMX 25.0% TNT
OCTONAL	49.0% HMX 29.0% TNT 22.0% Aluminum
CH-6	97.5% RDX 1.5% Calcium stearate 0.5% Polyisobutylene 0.5% Graphite
COMP A-5	98.5% RDX 1.5% Stearic acid
LX-14	95.5% HMX 4.5% Estane
PBXN-9	92.0% HMX 6.0% Dioctyl adipate 2.0% Hytemp
PBXW-11	96.0% HMX 3.0% Dioctyl adipate 1.0% Hytemp
PBXP-31	96.0% HMX 4.0% Silicone binder
PBXC-129	89.0% HMX 11.0% Lauryl methacrylate
PAX-2	80.0% HMX 12.0% NP 8.0% CAB
PBXW-120, Mod 1	79.0% HMX 21.0% FEFO/NPF-2
PBXW-120, Mod 2	79.0% HMX 21.0% FEFO/GAP
PBXN-5	95.0% HMX 5.0% Viton A
PBXN-6	95.0% RDX 5.0% Viton A

Explosive	*Composition*
PBXN-7	60.0% TATB 35.0% RDX 5.0% Viton A
PBXW-14	50.0% HMX 45.0% TATB 5.0% Viton A
B-2188A	44.0% PETN 40.0% HMX 16.0% Polyurethane binder
PBXC-18	95.0% ADNBF 5.0% Ethyl vinyl acetate

Appendix C

TYPICAL FAST COOKOFF RESULTS

VCCT FAST COOKOFF RESULTS

18 July 1995

Explosive type	Average density (g/cm^3)	Steel cylinder (in)	Burst pressure (psi)	External cookoff temperature (°F)	Internal cookoff temperature (°C)	Test result	Description
CH-6	1.65	0.015 wall	2,350	950	670	Fail	Sleeve finely fragmented, deformation of one plate, three bolts sheared.
CH-6	1.65	0.030 wall	5,230	1,150	640	Fail	Sleeve finely fragmented, deformation of both plates, bolts intact.
PBXN-5	1.73	0.045 wall	7,725	1,160	690	Pass	Sleeve recovered in two pieces, no deformation of plates, unreacted explosive.
PBXN-5	1.79	0.060 wall	10,000	865	670	Pass	Sleeve in one split piece, slight deformation of top plate, one bolt sheared.
PBXN-5	1.79	0.060 wall	10,000	1055	605	Pass	Sleeve in one split piece, no deformation of plates, no broken bolts, unreacted explosive.
PBXN-5	1.79	0.075 wall	12,700	950	650	Fail	Sleeve recovered in five pieces, deformation of both plates, one bolt sheared.
PBXN-5	1.79	0.090 wall	15,305*	1,000	690	Fail	Sleeve in three pieces, hole through one plate, deformation of other, two bolts sheared.
PBXW-11	1.75	0.075 wall	12,700	1,030	600	Pass	Sleeve in two pieces, no deformation of plates, unreacted explosive recovered.
PBXW-11	1.79	0.105 wall	17,634*	1,265	585	Pass	Sleeve in two pieces, no deformation of plates, all bolts sheared.
PBXN-7	1.77	0.105 wall	17,634*	1,200	715	Pass	Sleeve in one piece, no deformation of plates, two bolts sheared, unreacted explosive recovered.
PBXN-7	1.77	0.120 wall	19,963*	1,115	565	Pass	Sleeve in one split piece, slight deformation of top plate, one bolt broken.
COMP A-5	1.65	0.015 wall	2,350	1,190	755	Fail	Sleeve finely fragmented, deformation of both plates, cracking in top plate, two bolts sheared.
COMP A-5	1.65	0.030 wall	5,230	1,075	605	Fail	Sleeve finely fragmented, deformation of both plates, cracking in top plate, one bolt sheared.
LX-14	1.81	0.015 wall	2,350	1,310	No data	Pass	Sleeve in one split piece, no deformation of plates, bolts intact.
LX-14	1.81	0.060 wall	10,000	1,050	715	Pass	Sleeve in one split piece, no deformation of plates, bolts intact.
LX-14	1.81	0.075 wall	12,700	1,265	780	Pass	Sleeve in one split piece, no deformation of plates, bolts intact.
LX-14	1.81	0.090 wall	15,305*	1,185	650	Fail	Sleeve in one split piece, hole punched through top plate, cracking in bottom plate, bolts intact.

*Calculated value.

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6210 (S PETERS)	1
6210 (K RICE)	1
8510	3
8530	3
90	1
90A (BROWN)	1
90C (C DICKINSON)	1
90E (L ROSLUND)	1
90H (DUONG)	1
90I (B BAUDLER)	10
910	1
920 (R BERNECKER)	1
920 (DOHERTY)	1
920 (FORBES)	1
920 (TASKER)	1
920 (SANDUSKY)	1
930	1
930 (L LEONARD)	1
930 (C REAMS)	1
930 (KNUDSEN)	1
940	1
940 (TRAN)	1
940 (LAWRENCE)	1
940 (DENDOR)	1
9410 (E ANDERSON)	1
9410 (C GOTZMER)	1
9420 (M GALLANT)	1
950	1
950P (L MONTESI)	1
950T (M SWISDAK)	1
9510 (K BURROWS)	1
9510 (M BEYARD)	1
9510 (ALEXANDER)	1
9510 (GIBSON)	1
9530 (C PELETSKI)	1
9540 (L DAVIE)	1